Allocation Four Neighbor Exclusive Channels to Polyhedron Clusters in Sensor Networks

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Abstract. In sensor networks, due to the limited resources of sensor nodes, energy efficiency is an important issue. Clustering reduces communication between sensor nodes and improves energy efficiency by transmitting the data collected from cluster members by a cluster header to a sink node. Due to the frequency characteristics in a wireless communication environment, interference and collision may occur between neighboring clusters, which may lead causing network overhead and increasing energy consumption due to the resulting re-transmission. Inter-cluster interference and collisions can be resolved by allocating non-overlapping channels between neighboring clusters. In our previous study, a channel allocation algorithm is proposed. It allocates exclusive channels among neighbor clusters in various polygonal cluster networks. But, we have found that channel collision occurs among neighbor clusters in the process of applying the algorithm in complex cluster topologies. In order to complete the non-collision channel allocation, a straightforward algorithm which has not completed in the previous studies is proposed. We provide 4 rules for proving the proposed algorithm has no weakness. The result of experiment shows that our proposed algorithm successfully allocates exclusive channels between neighboring clusters using only 4 channels in a very complex cluster topology environment.

Keywords: Energy efficiency · Clustering · Inter-cluster interference · Non-overlapping channels · Four-color theorem

1 Introduction

Wireless sensor networks collect environmental data and are applied for various purposes such as intrusion detection in environmental monitoring of temperature and humidity, military areas, and area security. Sensor nodes become aware of the surrounding symptoms and transmit the measured data to sink nodes, which in turn analyzes the data. Due to the limited energy resources of sensor nodes, limitations arise on the wireless sensor networks. Many studies on the efficient use of energy have been done to overcome this problem [1–7]. In general, neighboring sensor nodes collect similar information, leading to large energy wastage due to duplicate transmission of similar information. As a result, many cluster methods on sensor networks have been

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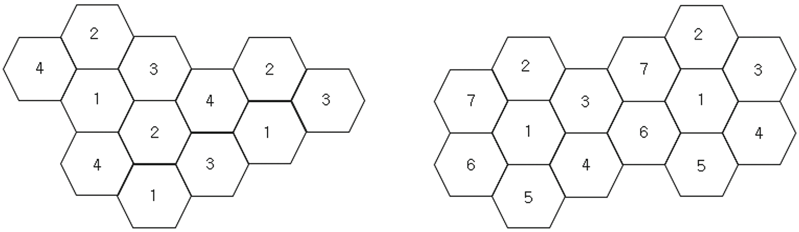
studied. Clustering, divides the sensor network into groups of nodes, is an effective method for achieving a high level of energy efficiency. In clustering, each node becomes a member of the cluster and the cluster headers aggregate data collected from members and then transmits it to a sink node. This prevents duplicated transmission of similar information and increases the energy efficiency of the sensor network [5–7].

Transmission synchronization between clusters can be done through non-overlapping channel assignments between neighboring clusters. Figure 1 shows the examples of channel reuse rate 4 and 7 [8, 9].



A. Channel reuse rate 4 B. Channel reuse rate 7

Fig. 1. Reuse rate in hexagonal models

In the Low-Energy Adaptive Clustering Hierarchy (LEACH) [1], representative clustering protocol for sensor networks, Transmission synchronization between nodes in clusters uses TDMA. Nodes located near the cluster boundary may interfere with the data transmission of another cluster node. Figure 2 shows that the transmission of the node which is located near the cluster boundary can interfere in data transmissions of the other clusters.

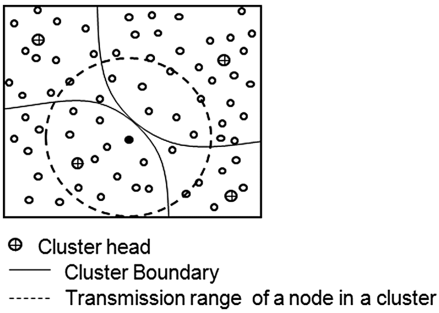


Fig. 2. Interference in cluster sensor networks

For inter-cluster synchronization in LEACH, each cluster communicates using different CDMA codes [1]. It is inefficient to implement CDMA code on low cost sensor nodes at cost.

TDMA-based Avoiding Collision (TAC) [10] uses TDMA to resolve inter-cluster synchronization. Cluster are assigned a different group ID between adjacent clusters and the group ID ranges from 1 to 4. The Initial cluster broadcasts a group allocation message including its own group ID. The clusters which receive it allocate the group ID which isn't same group ID. This process is continues until all clusters have group IDs in the wireless sensor network. This causes many control messages and delays for synchronization in the sensor network.

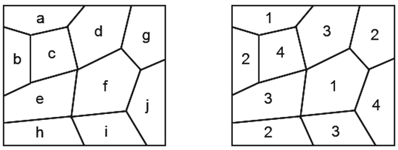
In [11, 12], an exclusive channel allocation based on matrices has been proposed. It assigns different channels between neighboring clusters based on the matrices, such as an adjacency, a topology and a resource allocation. The complicate calculations which are required for the exclusive channel allocation are made by a server with non-limited resource. Therefore, it doesn't require the exchange of many messages among sensor nodes. But this method is applicable in a hexagonal cluster topology, it may occur collisions among neighboring clusters in various cluster topologies.

In our previous study [13], the channel allocation method based on the four-color theorem [14–18] has been proposed. It allocates different channels among neighbor clusters in various cluster networks. It is very intuitive and simple to apply as compared to the previous methods which prove the four-color theorem. But, we found that channel collision occurs between neighbor clusters in complex cluster topologies. In order to complete the exclusive channel allocation algorithm which has not completed in the previous study, a local channel allocation method is studied [19]. But this process is very complicated.

In this paper, we propose straightforward algorithm to allocate exclusive channels in the neighbor clusters. The experiment shows that the enhanced algorithm successfully assigns non-overlapping channels between neighbors using only four channels in a very complicate cluster topology.

2 The Concept of Exclusive Channel Allocation

Non-overlapping channels among adjacent clusters can be assigned by only using 4 channels in some form of topology based on the four-color theorem. Figure 3(b) shows the result of the exclusive channel allocation using the four channel numbers 1, 2, 3, 4 in the topology of Fig. 3(a).



(a) Cluster topology (b) Channel allocation

Fig. 3. Cluster topology and the result of exclusive channel allocation

For non-overlapping channel allocation among neighbors in the cluster sensor network, we use the adjacency matrix A which presents the adjacency relation among clusters and the exclusive channel matrix EC which presents the result of exclusive channel allocation based on the matrix A.

(1) shows the A matrix of the cluster topology of Fig. 3(a). In the A, when two clusters are adjacent, the elements are represented by 'n' and two clusters are not adjacent the elements are represented by '0' [20]. (2) shows the EC matrix of the channel allocation of Fig. 3(b).

$$A = \begin{array}{c} \\ a \\ b \\ c \\ d \\ e \\ f \\ g \\ h \\ i \\ j \end{array} \begin{array}{c} \begin{array}{cccccccccc} a & b & c & d & e & f & g & h & i & j \end{array} \\ \begin{bmatrix} n & n & n & n & 0 & 0 & 0 & 0 & 0 & 0 \\ n & n & n & 0 & n & 0 & 0 & 0 & 0 & 0 \\ n & n & n & n & n & 0 & 0 & 0 & 0 & 0 \\ n & 0 & n & n & 0 & n & n & 0 & 0 & 0 \\ 0 & n & n & 0 & n & n & 0 & n & 0 & 0 \\ 0 & 0 & 0 & n & n & n & n & 0 & n & n \\ 0 & 0 & 0 & n & 0 & n & n & 0 & 0 & n \\ 0 & 0 & 0 & 0 & n & 0 & 0 & n & n & 0 \\ 0 & 0 & 0 & 0 & 0 & n & 0 & n & n & n \\ 0 & 0 & 0 & 0 & 0 & n & n & 0 & n & n \end{bmatrix} \end{array}. \tag{1}$$

The following EC shows the exclusive channel allocation matrix. In case of cluster a, the assigned channel is 1 and the neighbor channels are 2 in cluster b, 4 in cluster c and 3 in cluster d.

$$EC = \begin{array}{c} \\ a \\ b \\ c \\ d \\ e \\ f \\ g \\ h \\ i \\ j \end{array} \begin{array}{c} \begin{array}{cccccccccc} a & b & c & d & e & f & g & h & i & j \end{array} \\ \begin{bmatrix} 1 & 2 & 4 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 2 & 4 & 0 & 3 & 0 & 0 & 0 & 0 & 0 \\ 1 & 2 & 4 & 3 & 3 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 4 & 3 & 0 & 1 & 2 & 0 & 0 & 0 \\ 0 & 2 & 4 & 0 & 3 & 1 & 0 & 2 & 0 & 0 \\ 0 & 0 & 0 & 3 & 3 & 1 & 2 & 0 & 3 & 4 \\ 0 & 0 & 0 & 3 & 0 & 1 & 2 & 0 & 0 & 4 \\ 0 & 0 & 0 & 0 & 3 & 0 & 0 & 2 & 3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 2 & 3 & 4 \\ 0 & 0 & 0 & 0 & 0 & 1 & 2 & 0 & 3 & 4 \end{bmatrix} \end{array}. \tag{2}$$

The following shows the exclusive channel allocation algorithm. The notations for the algorithm are defined as follows;

The channel allocation formula (3) is used to assign non-overlapping channels among adjacent clusters. The channel allocation number is used in the range of from 1 to 4.

$$(3i + 2j) \% 4 + 1 \tag{3}$$

i, j are the channel numbers of the two reference clusters.

3 Channel Allocation Algorithm

<Rule 1> A non-overlapping channel can be allocated to a polygon cluster which has less than 3 allocated neighbors with different channel in the four-channel allocation problem at the polygonal cluster networks.

<Rule 2> To allocate non-overlapping channel in the entire area of a polygonal network, the channel allocated area of is extended by step by step. The boundary of the channel allocated area (i step, i >= 2) is adjacent less than 2-hop from the previous boundary. The minimum polygon is triangle, so un-allocated clusters which have adjacent more than 3 channel allocated neighbors can be avoided by this rule.

<Rule 3> In the extending of channel allocated area, a cluster of the 2-hop neighbors from the previous boundary can be selected as the followings; a cluster which already has 3 allocated neighbor is selected. By applying this rule to all adjacent clusters from the previous boundary, a new boundary of expanded allocated area is obtained.

<Rule 4> During the process of allocating channels in candidate clusters based on previous rules, a cluster which adjust sides to the allocated area boundary with more than 4 already allocated clusters can be appeared, then by switching channels between neighbour clusters, exclusive channels can be allocated among neighbours. Especially, when a cluster has aside 4 already channel allocated clusters, then the situation can be solved by changing with a channel that was allocated to the before procedure.

Exclusive Channel allocation algorithm is shown as follows;

1. Select one of cluster which has most many sides in the polygons as the start point and apply a channel.
2. In the clusters which are attached to already allocated area, a cluster which is attached most many sides is selected as a start point and non-conflictive channel with neighbours is allocated. In this case, most many sides of a cluster adjusted with the allocated area may be less than 3. Then select the next candidate cluster in clockwise or count-clockwise directions.
3. In each area expansion iteration, the channel allocated area must be expanded. The width of expansion is more than one cluster to outward from the allocated area.
4. All of the outward clusters those are adjusted with expanding allocated area must have not more than 2 adjusted sides, then an iteration of expanding allocated area is completed.
5. During an expanding allocated area, a case that an allocating candidate neighbour which may have more than 4 adjust sides from the allocated area is happen, then the candidate neighbour treated earlier than present cluster channel allocation or a local channel exchanging among clusters must be needed.

4 Network Operation

The cluster headers perform a central role in controlling networking such as synchronization, data collection, data transfer, so they consume a large amount of energy compared to member nodes. Before the energy of the cluster headers is exhausted, the selection process of new cluster headers is required. Therefore, clustering is performed periodically or re-clustering is required depending on the amount of energy remaining in the cluster header.

The operation is divided into rounds, as in LEACH [1]. Figure 4 shows the configuration of a round.

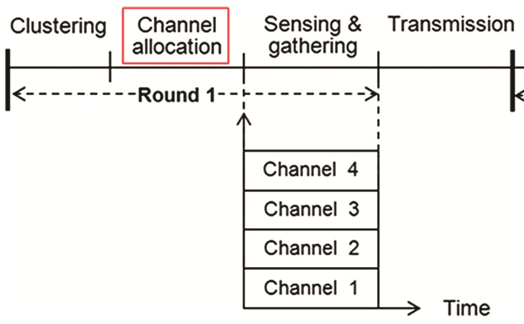


Fig. 4. Round configuration

The proposed algorithm is performed in a system with no constraints on system resources such as power, energy, memory, and processing capability.

In the channel allocation, cluster headers broadcast a hello message, The cluster headers which receive it recognize the existence of the neighbor cluster and generate the list of their neighbors and send it to a gateway or a server. The system performs a channel assignment algorithm for non-overlapping channel assignment.

5 Experiment

Performance evaluation experiments of the proposed channel assignment algorithm were performed. Figures 5, 6, 7, 8 and 9 shows that the process of channel allocation using the proposed algorithm. The numbers indicated in squares show allocation sequence. The numbers indicated in circles show the number of channels assigned to each cluster.

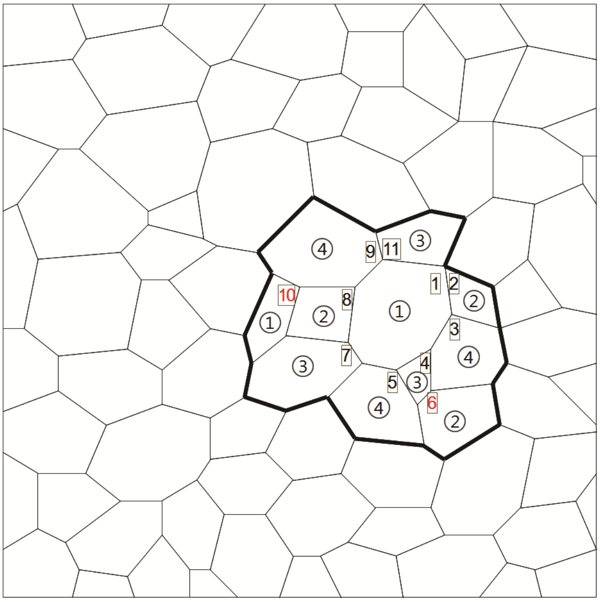


Fig. 5. Iteration result for the exclusive channel allocation area expansion (Color figure online)

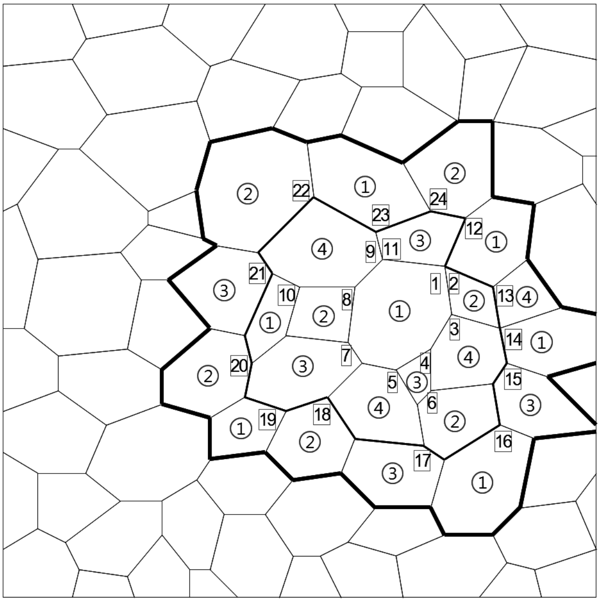


Fig. 6. Iteration result for the exclusive channel allocation area expansion

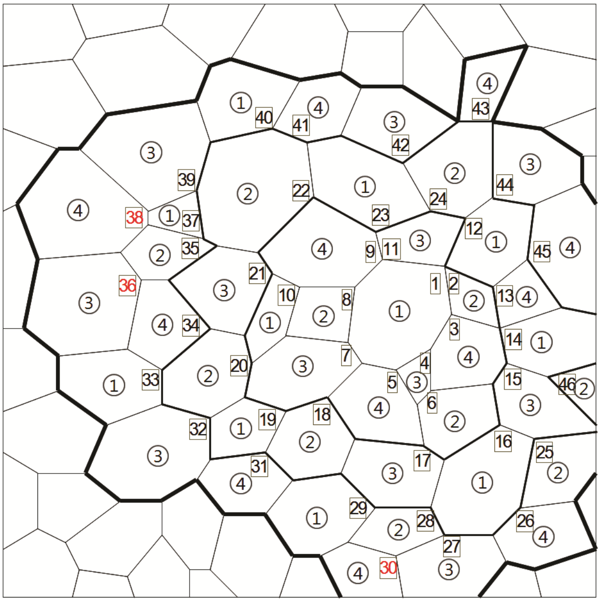


Fig. 7. Iteration result for the exclusive channel allocation area expansion (Color figure online)

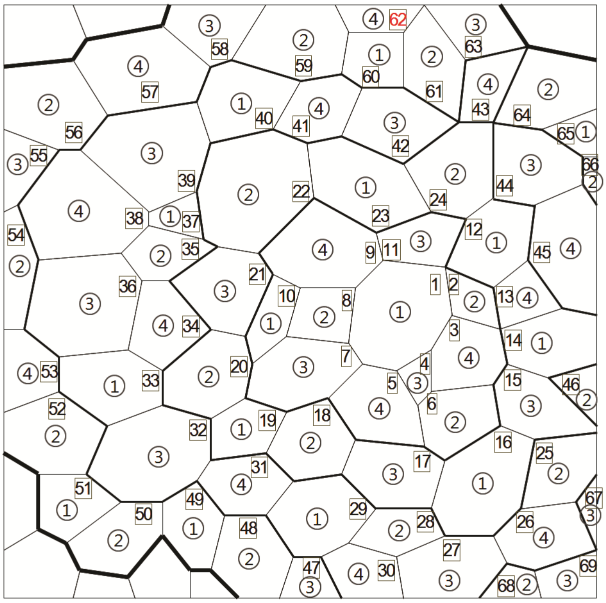


Fig. 8. Iteration result for the exclusive channel allocation area expansion (Color figure online)

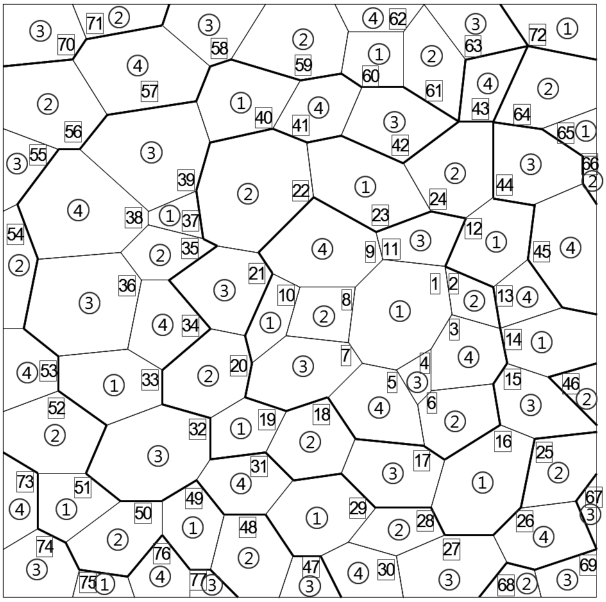


Fig. 9. Iteration result for the exclusive channel allocation area expansion

Figure 5 shows the first step of the channel allocation process. The cluster which has 8 neighbors is selected, and the channel 1 is assigned to the cluster. In the first step of the channel allocation, the channel which does not overlap is allocated to the one-hop neighbor clusters of the selected cluster. The channel 2 is assigned to one of the one-hop neighbor clusters of the first cluster. The channel 4 is allocated to the third cluster, based on the two clusters which are the first and the second cluster by the formula (3). This channel allocation process is continuously repeated based on the first cluster and the previous cluster allocated. After the fifth channel allocation, a non-overlapping channel is assigned to the cluster which has 3 neighbors to which channels are already assigned. The cluster isn't one-hop neighbor of the first cluster, but, a non-overlapping channel is allocated by rule 3. Again, a non-overlapping channel is allocated based on the first cluster and the previous cluster allocated. In Fig. 5, the red sequence numbers show the channel allocation by rule 3.

Figure 6 shows the second step of the channel allocation which allocates non-overlapping channels to one-hop neighbors of the first allocation area.

Figure 7 shows the third step of the channel allocation which allocates non-overlapping channels to one-hop neighbors of the second allocation area. The red sequence numbers show the channel allocation by rule 3.

Figure 8 shows the fourth step of the channel allocation which allocates non-overlapping channels to one-hop neighbors of the third allocation area. The red sequence numbers show the channel allocation by rule 3.

Figure 9 shows that non-overlapping channels are assigned to all clusters in the sensor network. The proposed algorithm successfully allocates exclusive channels between adjacent clusters by using four channels in a very complicate cluster topology.

6 Conclusions

The inter-cluster channel synchronization in the cluster-based sensor networks is important. To solve the channel conflicts of our previous study, we proposed the collision-free channel allocation algorithm.

The execution of the proposed algorithm shows the result of successful non-overlapping channel allocation between adjacent clusters in various and complex cluster topologies. As the future research, the practical protocol and procedures that can be applied in real cluster sensor networks must be studied.

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